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Land-Use Mapping by Machine Processing of LANDSAT-1 Data

Land-use maps of the City of Virginia Beach at a scale of 1:24,000 were produced using the LARSYS machine processing approach.

ABSTRACT: *Data on computer-compatible tapes of LANDSAT-1 MSS Frame E-1483-15132, of August 30, 1973, were analyzed to generate a land-use map of a portion of the City of Virginia Beach, Virginia. Bands 4, 5, 6, and 7 were used in the supervised approach with the LARSYS software system of Purdue University. A Land-Use/Land-Cover map at a scale of 1:24,000 was obtained. Major functional classes delineated were "Urban," "Agricultural," "Wooded," "Water," "Wetland," and "Bare Land." Twenty-four subdivisions of these classes were spectrally separable. Some of these were subdivisions of Level II of the Inter-Agency Steering Committee on Land-Use Information and Classification. Extent of man-made structures, unit density, and degree of weathering were important in subdividing the Urban class. In the Agricultural class, crop type was the most important factor. Vegetation types, age, and thickness of undergrowth were important in Woodland and Wetland areas; the depth, turbidity, and degree of algal and other pollution determined Water subclasses. Bare Land consisted mostly of beaches and mudflats. Performances of 97.9 percent for training field, 93.9 percent for test field, 97.0 percent for training class, and 92.1 percent for test class were obtained. Construction activities caused some misclassifications. The LARSYS software system was found to be useable in areas with complex land uses. The production of highly accurate functional land-use maps with the machine processing approach was found to be feasible.*

IN THE REPORT of the Committee on Remote Sensing for Agricultural Purposes (NAS, 1970), Luney and Dill noted: "Historically, land-use data have been compiled by census interviews or by field mapping. In some countries, major classes of land use are mapped in the field and published, usually on a small scale. For most countries, land-use data consist of data compiled by census from personal interview, mail questionnaire, study sample areas, or some combinations of these means. Generally, these methods take a relatively long time because the number of trained scientists is limited or because the number of less-well-trained people required is large. These factors account for the relatively long intervals between census projects in many countries."

While this situation is still true in some countries, it is rapidly changing in many others. In recent years, pressing needs for

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increased food production, environmental protection, and the preservation of prime agricultural land from encroachment of sprawling urban and suburban development have awakened the interests of many in the subject of land use and the problems it entails.

Some of the developments which have effected substantial changes in the situation described by Luney and Dill have been in the area of remote sensing. Better sensing and interpretation instruments and techniques have facilitated increased applicability of remote sensing to land-use inventory. Huson (1970) used remote-sensing techniques to delineate 12 major land-use categories in the Crati Valley, Italy. Allan and Alemayehu (1975) used rural land-use parameters as interpreted from 1:20,000-scale aerial photographs to estimate the population of a rural area 200km^2 in Wolamo, Ethiopia; and Keech (1974) was able to make an almost complete farm plan on aerial 1:20,000 photographs for the "European" farmers in Rhodesia.

Remote-sensing techniques also have been used in urban area land-use analysis. Wray (1948) used aerial photographs to develop an atlas of Chicago Municipal Airport. Pownall (1950) explained an early remote-sensing attempt at urban land-use classification in which land-use areas categorized as commercial, recreational, and vacant were keyed on the basis of tone, texture, stereo appearance, pattern, distribution, and associative characteristics. Witenstein (1954, 1956) studied Rockville, Maryland over a number of years and classified urban areas according to function, structure, type, and density of roof coverage patterns.

In recent years considerable attention has been shifted from what has become known as "conventional" aerial photography to small-scale high-altitude and space photography. These have been applied to land-use classification in both rural (Vegas, 1972; Alexander, 1973b) and urban (Alexander, 1973a; Simpson *et al.*, 1974) areas. In addition, machine-processing techniques have been developed for interpretation of remote-sensing data. Fitzpatrick and Lins (1973), Wilson and Petersen (1973), and Joyce (1974) have used these techniques in rural

FIG. 1. General map of the study area showing major drainage and communication routes.

FIG. 2. Band 7 of LANDSAT-1 MSS image of August 30, 1973. The study area is outlined.

land-use analysis; and Borden *et al.* (1973) and Ellefsen, Swain, and Wray (1973) have applied the same techniques in urban areas. The study reported here applied these techniques to the City of Virginia Beach, Virginia.

The study area is located in the southeastern tip of Virginia. It has a total area of 803km², 83 percent (67,000ha) of which is land. Of that, only about 12,000ha consist of well-drained soil (Simmons and Shulkcum, 1945). Less than one-half of the well-drained soils remain in agriculture.

The population of the city increased from 172,106 in 1971 to an estimated 210,000 in 1974, and is projected to reach 300,000 by 1990. The land use in the area is thus changing very rapidly, mainly from the relatively uniform agricultural to the more complex urban.

The study was therefore conducted with these objectives: (1) to test the applicability of the LARSYS pattern recognition software for land-use mapping in this rapidly changing and complex environment, and (2) to determine the feasibility of producing an operational land-use map by using the machine analysis approach. The latter can effect a substantial saving in time required for analysis and interpretation, and at the same time generate land-use maps that are more detailed than the currently existing ones.

MATERIALS AND METHODS

The City of Virginia Beach, Virginia, comprising the recently incorporated (1963) Princess Anne County, lies in the Coastal Plain physiographic division in the Tidewater Section of Virginia. Although some dunes at Cape Henry are as high as 26 metres above sea level, few places are above 6 metres. Relief of as much as 6 metres occurs locally in the northern one-third of the city, and substantial areas of the city are within 3 metres of the mean sea level. The major drainageways and communication routes and the location of the study area are shown in Fig. 1.

Although the southern half of the city is predominantly agricultural, the urbanized area is rapidly advancing southward. Limited agricultural activities persist in the more urbanized northern one-third of the city, but these are rapidly succumbing to urbanization.

The remote-sensing data used were those of the LANDSAT-1 (ERTS-1) Multi-Spectral Scanner (MSS), obtained August 30, 1973

(Figure 2). Only the portion of the city included in this scene (about three-fourths of the total area) was analyzed. Because the major thrust of the research utilized machine processing, the use of the visual form of LANDSAT imagery was limited. Rather, the computer-compatible tapes (CCT) containing the original electro-optical digital data were used directly. All the four bands of the MSS were utilized in the analysis. The principles and operation of the LANDSAT equipment have been described in several NASA publications (Wolff, Cote, and Painter, 1975) and the fidelity of these data have been investigated and evaluated in previous research (Colvocoresses, 1970; McEwen, 1973). Low-altitude aereal photographs and medium scale topographic maps were used to aid in ground data verification.

Analysis was conducted through a 2780 remote terminal located at the NASA Wallops Flight Center. This terminal is connected to the Central Processing Unit (CPU) located at the Laboratory for Applications of Remote Sensing (LARS), Purdue University, West Lafayette, Indiana.

The software employed is the LARS-developed LARSYS pattern-recognition package. It is a "fully documented software system for installation on a general purpose computer to provide tools for remote sensing research" (Phillips, 1973), and is fully described in the three volumes: "LARSYS Users Manual" (Phillips, 1973). The results of the supervised classification approach are described in this paper.

After examination of the topographic maps, low-altitude imagery, and an on-site inspection of the study area, six tentative land-use test classes were selected. These

Symbol		Land-Use Map
+	equal	Urm
2	"	Uc
-	"	Url
A	"	Aw
C	"	Ac
#	"	As
I	"	Ap
Y	"	Fy
Z	"	Ft
R	"	Fr
L	"	Ws
K	"	Wr
B	"	Wb
Q	"	Ww
W	"	Wc
M	"	Wo
X	"	Mp
F	"	Mf
S	"	Ms
*	"	Mb
/	"	Mn
@	"	Bs
.	"	Bl
$	"	Bm
Blank	"	Thr

FIG. 3. LARSYS Ver. 3 classification printout. The outlined area is represented in Figure 4.

were "Urban," "Agricultural," "Wooded," "Water," "Wetland," and "Bare Land." These were later retained.

A total of 110 training fields with 4854 data samples (pixels), and 32 test fields with 3025 data samples were developed for the six test classes. No upper limit was set in advance concerning the number of training and test fields to be used. Rather, the training fields for each test class were randomly selected and were scattered throughout the study area. The 4854 figure was arrived at after initial clustering and refinement of the training fields. These data samples were distributed as follows: Urban-237, Water-2937, Wetland-761, Wooded-174, Agricultural-618, and Bare Land-127. The test fields also were distributed throughout the study area.

The selected training fields for each test class were refined by clustering them into "twice the expected subclasses" (Lindenlaub, 1973). Through this process, a total of 24 subclasses were derived for the six test classes.

The four-page line printer output map obtained from the final classification was overlayed with glazed acetate and the land-use classes were delineated on the acetate. In this way, the classified pixels were generalized into hand-drawn land-use polygons. In consideration of the clarity and legibility of the hand-drawn map, it was arbitrarily decided that three contiguous similarly classified pixels would be the smallest separate delineation. The units of the maps, which correspond to the subclasses of the classification process, were coded with either two or three letter symbols, depending on whether the unit corresponded to Level II of Anderson *et al.* (1972) or whether it was a subdivision of a Level II unit.

Results and Discussion

Performance statistics obtained in the final classification were high, and because all the test fields were ground-checked (a light plane was used for inaccessible areas), this is interpreted as indicating a highly accurate map. In addition, the map was evaluated at random points throughout the study area. The training field performance was 97.9 percent and the test field performance was 93.9 percent. The average performance by class for training class was 97.0 percent, while that for the test class was 92.1 percent. A sample printout map of this classification is given in Figure 3. Separation at Level II (Anderson *et al.*, 1972) was achieved for all the six Level I land-use classes in this area, and Level III was also achieved for a few of the classes.

FIG. 4. Portion of the functional land-use/land-cover map derived from the machine processed printout map. Symbols are explained in Table 1.

The sub-divisions of the various Level I classes, which are the 24 cluster classes, were achieved on the basis of the characteristics summarized below. These characteristics were evaluated after the classification

(1) The Urban class was found to contain a wide variety of cover types with various optical reflectance characteristics. These included concrete and asphalt surfaces; roofs of various colors; a variety of lawns and ornamental trees; both highly weathered and relatively new industrial sites; and an assortment of tennis courts and swimming pools. The separation into three subclasses was achieved on the basis of the extent and density of man-made features and on the degree of their weathering.

(2) Of the six Level I land-use classes in the study area, the Agricultural class was, relatively, the most homogenous. Four agricultural subclasses were delineated. These were areas in corn (Zea mays), in soybeans (Glycine max), in transition from winter wheat (Triticum aestivum) to no-till soybeans, and in pasture and other grassland areas. Minor crops of the area, such as sweet potatoes, irish potatoes, strawberries, and other vegetables, were included in one or more of these subclasses.

(3) The Wooded and Wetland classes were subdivided into three and five subclasses, respectively, on the basis of the age,

height, amount of branching and leafiness, and the amount of understory vegetation. Forested and non-forested wetlands were delineated.

(4) Six subdivisions of the Water class were obtained on the basis of its turbidity with respect to suspended inorganic and organic sediment, presence or absence of algal growth, extent of weed growth, depth, and relative calmness.

(5) The Bare Land class was subdivided into three subclasses. These were bare sandy beaches, partially vegetated beaches and inland sand, and bare tidal mudflats.

A portion of the functional land-use/land-cover map obtained in the study is reproduced in Figure 4. By printing every pixel, a map of 1:24,000 scale is obtained by machine processing of the satellite data acquired at the small scale of 1:3,369,000. The legend of the map, explaining the symbols used in the map is shown in Table 1. The subclasses explained above formed the delineated units of the map.

Characteristics of the Machine Processed Map

In the traditional land-use mapping methods, functional classes are assigned on the basis of the recognition and interpretation of the scene. In machine processing, the classification is based solely on similarity in spectral reflectance characteristics. Spectral classes do not always correspond to functional classes. Relative homogeneity in

Table 1. Legend of the Land-Use/Land-Cover Map Produced by Machine Processing of LANDSAT-1 MSS Data

Map Symbols	Explanation
Urban Areas	
Urm	Medium Density Single Family Residential with 15-22 Units Per Hectare, (7-10 u/ac)
Uc	Extensively Paved Commercial Centers. Includes Drive-In Theaters and Large Warehouses
Url	Low Density Single-Family Residential with 4-14 Units Per Hectare, (2-6 u/ac)
Agricultural Areas	
Aw	Areas in Transition From Wheat to Late No-Till Soybeans
Ac	Corn Fields
As	Dense, Green, and Leafy Early No-Till Soybeans
Ap	Pasture and Other Grass Land Areas. Includes Golf Courses, Playing Fields, and Some Lawns.
Wooded Areas	
Fy	Young Forests, Mostly in Recently Abandoned Agricultural Lands, with Moderate to Sparse Undergrowth
Ft	Transitional Areas from Agricultural to Urban with Short Bushes and Tall Grasses
Fr	Old Residential Subdivisions in Which Ornamental and Climax Vegetation Almost Completely Cover the Houses and Streets
Water Areas	
Ws	Shallow Water Along Coastline, Submerged Shoal and Sandbars, and Areas of Cloud Cover
Wr	River and Canal Water
Wb	Bay Water in Chesapeake Bay; Including Lynnhaven Bay, Broad Bay, and Little Creek
Ww	Waters of Back Bay with a Thick Growth of Weeds
Wc	Clear Non-Ocean Water of Lakes, Inland Ponds and Some Parts of Back Bay
Wo	Atlantic Ocean Open Water
Wetland Areas	
Mp	Highly Branched, Moderately Tall Wetland Forest with Thick Undergrowth
Mf	Tall, Stemmy, Mature Hard Wood-Pine Mixture with Thin Understory
Ms	Sea Shore State Park Vegetation Mixture
Mb	Short, Thick, Discontinuous Patches of Salt-Tolerant Bushes
Mn	Non-Forested Wetland Areas Dominated by Various Salt Marsh Grasses
Bare Land Areas	
Bs	Highly Reflective Beaches and Other Excavated Areas Devoid of Vegetation
Bl	Partially Vegetated Lee-Wards of Beaches and Similar Inland Areas
Bm	Wet Mudflats and Tidal Flats Very Sparse in Vegetation
Other Areas	
Thr	Isolated Areas of Unique Land Uses Whose Characteristics Are Dissimilar to All Others

TABLE 2. SPECTRAL RESPONSE COMPONENTS OF THE MAJOR LAND-USE CLASSES

Functional Classes	Spectral response component sources
Urban	Highly reflective concrete surfaces, light brown to white walls and roofs; low reflective asphalt surfaces, dark brown to black roofs and walls. Red walls, landscaped lawns and playgrounds, and numerous species of ornamental trees of all ages. Automobiles, shipping harbors and railroad yards.
Agricultural	Various agricultural crops: corn, soybeans, wheat and wheat stubble, barley, oats, and potatoes. Nurseries, lawns, playing fields, golf courses, pastures, and parks. Scattered areas of vegetable and truck crops. Isolated farmhouses, barns and other farm structures.
Wooded and Wetland	Numerous species of hardwoods and evergreens, brushes and grasses of various heights and ages, leaf geometry, and leaf area indexes. Flowers of various pigmentations.
Water	Suspended mineral and organic sediment, water weeds, algae, oil slicks, and sandy beds.
Bare Land	Highly reflective bare sand, low reflective organic and mineral mudflats, and clumps of salt-tolerant grasses.

spectral characteristics is best achieved in agricultural fields during the growing season (LARS, 1970). At the other end, maximum diversity is obtained in urban areas. In all cases, the class based on spectral characteristics incorporates an interplay of all the spectral characteristics of all the component members of the class population. Contribution to the integrated "picture" depends on the frequency of the members of the population and on their other physical characteristics. The members of the population will depend on the area being classified.

Some of the components of the classes identified in this study are summarized in Table 2. The Urban class is the most complex. It requires the combination of several basically different ground cover classes into a single land use. For example, single family residential use is composed of such spectrally diverse features as asphalt streets; concrete drives, patios, and stairs; roofs of various colors; varying stages of maturity of landscaping; churches; schools; vehicles of many sizes and colors; and swimming pools. Even when the single family class is subdivided on the basis of density, a measure of units per land area, the interplay of these components is not minimized. Successful classification of the urban class is largely achieved because of the general tendency for a specific urban function to be conducted in a specialized urban environment.

Although relatively the most spectrally homogeneous, many factors must be considered in classifying agricultural areas on the basis of their spectral response characteristics. These factors have been investigated (LARS, 1968) and include plant geometry, planting technique, row direction, date of planting, date of harvest, variety of crop species, species and crop use, and other agricultural patterns. Some of these may be more or less important depending on the time in the growing season the data are obtained. Thus, if the goal in agricultural land-use classification is discrete crop identification, the remote-sensing data taken specifically for this purpose should be taken at times when the different agricultural crops exhibit maximum spectral homogeneity.

COMPARISON WITH THE USGS PROPOSED SYSTEM

The U.S. Geological Survey (Anderson *et al.*, 1972) proposed a land-use classification system for use with remote sensor data. The system has levels of generalization I, II, III, and IV; the more discrete higher level use categories are collapsible into the more general lower classes. The system was developed on the assumption that different sensors will provide information for different levels of classification. It was anticipated that Level I would require "satellite imagery, with very little supplemental information;" Level II would require "high-altitude and satellite imagery with topographic maps;" Level III would require "medium-altitude remote sensing (1:20,000) combined with detailed topographic maps and substantial amounts of supplemental information;' and Level IV would utilize "low-altitude imagery with most of the information derived from supplemental sources." Manual methods of imagery interpretation were assumed. Indeed, the au-

TABLE 3. COMPARISON OF A LAND-USE CLASSIFICATION DERIVED FROM MACHINE PROCESSING OF LANDSAT-1 MSS CCT DATA WITH U.S.G.S. PROPOSED LAND-USE CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA

Machine-processed LANDSAT-1 Data	U.S.G.S. Proposed System Level I	Level II
1. Urban	01. Urban and Built-up	
Medium Density	01. Urban and Built-up	01. Residential
Residential	01. Urban and Built-up	01. Residential
Low Density	01. Urban and Built-up	01. Residential
Residential	01. Urban and Built-up	01. Residential
Commercial	01. Urban and Built-up	02. Commercial and Services; 03. Industrial; 04. Extractive; 05. Transportation, Communications, and Utilities 06. Institutional; 07. Strip and Clustered Settlement; 08. Mixed
2. Agricultural	02. Agricultural	
Wheat Stubble	02. Agricultural	02. Cropland and Pasture
Corn Fields	02. Agricultural	02. Cropland and Pasture
Soybeans	02. Agricultural	02. Cropland and Pasture
Pasture	02. Agricultural	02. Cropland and Pasture
3. Wooded	04. Forest Land	
Young Forests	04. Forest Land	01. Deciduous;
	04. Forest Land	02. Evergreen (Coniferous and Other); 03. Mixed
Transitional Areas	04. Forest Land	03. Mixed
Forested Residential	01. Urban and Built-Up	01. Residential
4. Water	05. Water	
River and Canal	05. Water	01. Streams and Waterways
Lakes, Ponds	05. Water	02. Lakes; 03. Reservoirs
Bays	05. Water	04. Bays and Estuaries
Shallow Coastline Water	05. Water	05. Other
Ocean	05. Water	05. Other
5. Wetland		
Peripheral	04. Forest Land	03. Mixed
Forested	04. Forest Land	03. Mixed
Seashore State Park	04. Forest Land	03. Mixed
Salt Bushes	06. Nonforested Wetland	01. Vegetated
Nonforested Wetland	06. Nonforested Wetland	01. Vegetated
6. Bare Land	07. Barren Land	
Mudflats and Tidal Flats	07. Barren Land	01. Salt Flats
Bare Beaches	07. Barren Land	02. Beaches
Partially Vegetated Beaches	07. Barren Land	02. Beaches

thors asserted that "... classification of land use from imagery will remain a personal task for an indefinite period of time and will only gradually become semiautomatic process and perhaps eventually a fully automatic procedure."

For manual interpretation, the LANDSAT-1 imagery usually is enlarged to a scale of 1:1,000,000 or larger from the 1:3,369,000 scale. However, when machine analyzed directly from the CCT's, each resolution pixel (1.1 acres or 0.45ha) can be discretely classified. When every pixel is printed, the 1:24,000-scale printout map overlays the standard USGS 7.5 minute quandrangles. Thus, as long as the spectral classes can be related to functional land-use classes, more detailed information can be extracted from these data by machine processing. Comparison of the results of this classification with the recommended scheme is given in Table 3. It demonstrates that for the area studied, this assertion can be substantiated.

Conclusions

The study applied one of the recently developed machine processing techniques for remote sensing analysis. The LARSYS software system was developed and tested for classifying mainly agricultural land uses, and has also been employed in many non-agricultural areas. The present study has shown that the system can be successfully used in areas with complex land uses. With adequate ground data, accuracies substantially better than the 85 to 90 percent normally accepted by users of land-use information can be obtained via the supervised approach. In addition, the study has shown that, compared to the techniques mentioned by Luney and Dill (NAS, 1970), the machine analysis approach can effect substantial saving in investigation time while at the same time improving the accuracy of the product. Also, the feasibility of producing functional land-use maps through the machine analysis approach has been demonstrated.

Other possibilities have also been indicated by the results of this study. Quantification of land-use data or changes in land-use seems to be feasible because the land area of the pixel is known. The high speed attained in the interpretation of the data is likely to make temporal comparisons easier and faster, especially with the repetitive coverage of LANDSAT. The machine analysis approach reduces bias in classification, and the inherent digitizing of the data facilitates data storage and various forms of retrieval.

The "Land Use Classification System for Use with Remote Sensor Data" proposed by the USGS was found to cover adequately the land uses of the area studied with only minor modifications. Results obtained in this study indicate that the proposed USGS system and the LARSYS software could be used together for natural resource inventorying on a regional basis.

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